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James E. Nielsen, District Silviculturist

Powers Ranger District

Siskiyou National Forest

June , 1985

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EXPERIMENT STATION

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INTRODUCTION

Properly prescribed precommercial thinning (PCT) is one of the most important timber stand improvement activities affecting future stand development and yield. Done without adequate consideration for future management needs, however, PCT can fail to gain expected benefits or result in abnormal stagnation and mortality (Reukema, 1977).

The purpose of this paper is to describe factors (silvicultural, economic and others) which should be considered during PCT silvicultural prescription preparation. The analysis is based on research, discussion with knowledgeable people and generally accepted knowledge based on operational experience. Field sampling has been done to test concepts rather than to develop new information. The recommendations and described factors are intended to guide PCT prescription development on the Siskiyou National Forest, in stands that are predominantly (70%+) Douglas-fir. The requirements of other species such as Port Orford cedar, ponderosa pine and sugar pine must be considered in addition to these factors. The results of this paper are probably applicable to other westside Forests in Oregon and Washington.

This paper is intended to build upon the work done by Reukema (1975) and it is recommended that this publication be reviewed as part of the prescription development process. The value of properly applied precommercial thinning is accepted without further analysis.

LOGGING SYSTEM ECONOMICS AND MARKET VALUE CONSIDERATIONS

One of the most important factors affecting PCT spacing is the economic efficiency of the first commercial entry. For thinning, this is of critical importance to avoid having the land manager incur an additional investment cost in order to avoid stagnation and achieve acceptable stand development. Integration of the stand management options of precommercial thinning, fertilization, harvest entry timing, logging equipment selection and thinning intensity must be accomplished to avoid the above consequence and maximize financial yields. (Le Doux and Brodie - 1982).

Since it will be 20 to 40 years before the stands now planned for PCT will be commercially thinned, futuring to estimate management needs at that time is necessary. Tedder (1979) estimates that future harvest levels in Oregon will be somewhat lower than those at present but that harvested tree diameters will drop significantly, particularly for Forest Industry managed lands. This ownership group will see average harvested tree diameter fall from 27 inches in 1975 to approximately 10 inches in 2015. In this same time period average harvested diameters in National Forest (Western Oregon) will remain relatively unchanged while that of all ownerships in Western Oregon will decline from 23 to approximately 18.5 inches. The implications of these forecasts is that smaller logs will be more readily accepted at tributary mills and that harvest machinery specializing in small logs will be common.

Logging Equipment And Methods

Based on these projections, and logging systems research, PCT spacing prescriptions should be based on the operational use of the following types of machinery and logging methods at the first commercial thinning (CT):

1. Small inexpensive (less than $100,000) yarders such as the Igland Jones Trailer Alp and Koller K-300.
2. Multi span yarding (Kellogg - 1981).
3. Prebunching and swinging if more expensive yarders are used (Kellogg - 1981).
4. Tree length or whole tree yarding (Putnam - 1983).
5. Hot Thinning (Kellogg - 1984) (simultaneous felling and yarding).
6. Mechanical fellers such as the Kaiser Spider which are adaptable to steeper slopes where soil conditions permit their operation.

Planning for multi span skyline yarding during commercial thinning is particularly important because this logging method allows greater reaches over convex or broken topography. Use of a double tree support system eliminates the need for additional guylines and reduces the cost of road changing. Of significance is the Oregon Safety Code recommendations for these intermediate supports. With loads between 5,000 and 6,000 pounds, support trees need to be 12 inches diameter or greater if rigging heights are less than 30 feet. Rigging heights between 30 and 40 feet require 14 inch diameter support trees. (Kellogg - 1981).

Over the next 20 to 40 years these systems will be improved and new ones developed, but dramatic changes are not expected since logging has not been on a high technology development track. (Garland - 1984PC) (Kellogg-1984PC).

Yarding Distance

Consideration during the PCT prescription process must be given to maximum economic yarding distance for commercial thinning. Existing studies do not analyze stands with external yarding distances greater than 1200 feet.

One study (Sessions - 1979) indicated that volume thinned at 1200 feet is worth less than its logging cost and is being subsidized by logs closer to the landing. In fact, it was found that present net worths are higher if only the first 300 feet is thinned and the remaining 900 feet left unthinned. These distances, of course, will vary somewhat according to market conditions.

Loren Kellogg (1984 PC) was personally consulted regarding what probable external yarding distances will be economic in 20 to 30 years. His recommendation is that approximately 1200 feet should be considered a maximum for present PCT planning purposes. Beyond this distance, prescriptions for PCT spacing should consider that future commercial thinnings are not likely and that significantly fewer crop trees per acre should be left (Reukema - 1975).

Tree Size And Logging Cost

Even with the most efficient combination of the previously described logging systems, tree size and accompanying stand density will have a major effect on the economic efficiency of the first commercial thinning. A number of studies (Sessions - 1979, Kellogg - 1983, Le Doux - 1981 and others) indicate that costs

rise significantly as average stand diameter decreases. For example, a comparison of two stands studied for logging cost (8" and 12" average DBH) revealed that the average volume per tree in the smaller was one half that of the larger and that the former had 80 percent higher felling and bucking costs (Kellogg 1983). The greater stand densities associated with smaller diameter stands causes increased felling costs because of a greater number of hang ups (Kellogg - 1980, 1984). Smaller piece sizes require a greater number of logs to utilize the weight capability of logging systems. Under these circumstances underloading is a problem with most logging systems used for commercial thinning and is a particular problem with skyline systems due to their greater costs (Kellogg 1983). Tractor logging is significantly less expensive than cable. In one logging cost study (Aulerich, et al - 1974) it was found that stumpage values for tractor logging were $30 to $40 per MBF greater than cable. Tree size then, has a very large effect on logging economics particularly when cable yarding is employed. (Sessions 1979, and others).

Product Value

In terms of saw logs, mill value will not be a large factor since most logs removed in a first commercial thinning will be classified either #3 or #4 mill. Sessions (1979) found that in 1978 mill values were $215/M for #4 mill logs (<6" scaling diameter) and $230/M for #3 mill logs (<12" scaling diameter). This difference in value is significant but the limits for #3 mill logs are wide and the difference between #3 and #4 mill logs is not great when compared with the difference in logging costs between large and small logs ($40 to $50 per MBF - 10" vs. 14" mean stand DBH)(based on interpretation of charts from Sessions - 1979).

Another option to consider is the production of chips or wood fiber from on site processing of harvested material. The Washington State DNR performed a case study to determine the feasibility of this method of utilization (Kammenga - 1983). The operational method found most efficient was a combination of a portable chipper, chain-flail delimber, two rubber tired grapple skidders and three rubber tired or tracked tree-to-tree feller bunchers with accumulators. Whole trees were yarded and chipped with saw logs and fuel material sorted for separate utilization. Power saw felling was found to be slow and created additional work during the yarding phase. One half acre landings were found necessary to accommodate the chipping operation. There may be some areas on the Siskiyou National Forest with terrain and soils suitable for this type of operation. On the Powers District, cable yarding of hardwoods was used to supply a chipper. The operation proved inefficient due partly to the disparate production rate of the chipper and the cable yarding operation.

Desirable Tree Size

In determining desirable tree size at the first commercial thinning, two factors must be weighed. The first is harvest economics which strongly indicates that larger trees are more efficient to harvest and utilize. The second, is the potential yield decreases resulting from increased spacing of crop trees following PCT. This factor is further discussed under the section Yield Considerations. Based on the foregoing, however, it seems logical to increase stand diameters up to the point where total stand yield begins to decrease and then perform an economic analysis to determine how much of a yield decrease can be accepted to achieve still larger diameters compatible with other values.

In order to make the above analysis a stand projection model such as DFSIM must give yield data which is reliable and acceptable at stocking levels less than 300 trees per acre following PCT. Since we don't have this capability available to us Loren Kellogg (1984 PC) was consulted in regard to desirable stand diameters. He recommended, as a stand management objective, production of 12" average diameter excess trees at the first commercial thinning. With a moderate intensity thinning (d/D ratio of .9) this would result in desirable average total stand diameters of approximately 13.5 inches. A stand management objective to produce average stand diameters of 13" to 14" DBH at the first CT would seem to satisfy logging economics concerns and seems intuitively correct to anyone who has witnessed a load of smaller logs prepared at a landing.

STAND DENSITY CONTROL CONSIDERATIONS

Stand Density Index Selection

Based on the foregoing economic considerations, it is desirable to manipulate precommercial thinning spacing (PCT) so that the treated stand will have an average DBH of 13 to 14 inches at the time of first commercial thinning. In order to do this, a stand density control system must be used which can integrate trees per acre (TPA) and desirable average DBH with a valid determination of excessive intertree competition. There are a number of competition indexes which can do this. The ones examined for this analysis are: Reineke's Stand Density Index (SDI) (Reineke - 1933), Curtis's Relative Density (RD) (Curtis - 1982), Drew-Flewelling Density Management (D-F) (Drew, Flewelling - 1979) and Growth Basal Area (GBA) (Hall - 1981). The DFIT and DFSIM stand projection models can be used to assess the effects of stand density but are not competition indexes to be compared with the others. Both DFIT and DFSIM (default option) use a relative density (RD) of 50% to control the timing of the first commercial thinning. DFSIM with multiple runs and specified ages can be manipulated to achieve a commercial thinning at a desired relative density other than 50%.

SDI and RD are simply different ways of expressing the same relationship between average diameter, trees per acre and maximum stand density. The following field plot data demonstrates the degree of correlation between these two indexes:

TABLE I

Plot #	Quad. Mean Diam.	Basal Area/ Ac (Ft^2)	Trees/ Acre	SDI	RD
1	5.7"	124	700	47.9%	51.9%
2	8.1"	214	600	72.0%	75.2%
3	10.9"	130	200	38.6%	39.4%
4	12.8"	300	334	83.3%	83.9%
5	15.1"	360	288	93.6%	92.6%
6	15.8"	220	161	56.3%	55.3%
7	16.4"	200	136	50.4%	49.4%

Drew-Flewelling's Density Management index (D-F) is closely related to the above except that tree height and stand diameter are integrated thru average tree volume (Ft^3) and substituted for average stand diameter. The correlation between these three indexes is shown in the following table. This data is derived from DFSIM projections for trees 7.6 inches DBH and greater. Each "stand" was precommercially thinned to 300 crop trees per acre.

TABLE 2

Site Index 100 yr. Base	DBH	Basal Area/ Ac(Ft^2)	Trees/ Acre	Cubic Vol. Top & Stump	RD	SDI %	D-F %
110	12.6	211.4	245	6709	59.6%	59.6%	48.4%
120	13.2	222.3	235	7594	61.2%	61.6%	51.9%
130	13.3	221.9	229	7820	60.8%	60.7%	52.4%
140	13.4	218.9	225	7888	59.8%	60.4%	52.4%
150	13.9	230.5	218	8891	61.8%	62.1%	56.2%

These projections indicate that Drew-Flewellings relative density appears to be 6 to 10% less than SDI and RD. This difference is significant and will be discussed later.

Growth Basal Area (GBA) is a site stockability system based on the assumptions that diameter growth is inversely related to basal area and that GBA changes can be indexed to stand age. A computational slide rule has been developed which, among other things, determines a desirable number of trees per acre following PCT based on user specifications and that site's GBA.

Curtis's Relative Density is recommended for the following reasons:

1. Its basic formula ($RD = G/D^{1/2}$) is simple and easy to use.

2. Relative densities determined by SDI and RD are nearly identical.

3. RD has been incorporated into the default regime of DFSIM and this program (DFSIM) can be manipulated to achieve a RD of the users choice. Modification of DFSIM to make this selection direct would be useful, however. Use in DFSIM will most likely lead to greater application and acceptance of RD increasing the value of its index numbers.

4. A well correlated relationship between RD and the crown competition factor (CCF) index has been established. (Curtis - 1981).

5. As with SDI and D-F, RD is independent of age, site quality and management actions (Daniels - 1984).

Growth basal area receives wide acceptance and use on the Siskiyou National Forest but for setting PCT spacing RD is recommended since, in addition to the above, GBA cannot be determined directly for plantations 10 to 20 years of age (prime candidates for PCT) due to rapid change in basal areas for these young stands (Hall - 1981). Indirect methods such as measurement prior to regeneration harvest, determination of GBA from adjacent stands and determination of GBA from stumps within a plantation are possible. In some cases, however, these methods are time consuming or will not yield valid results due to specific site differences and the differences in growth pattern from old growth to second growth timber.

Some knowledgeable people feel that RD is too simple and not as biologically real as other indexes. Daniels (1984) would disagree and state that Reineke's stand density index (equivalent to RD as shown earlier) is fully capable of accurately expressing density relationships. Curtis (1981) has expressed the opinion that most density indexes are similar and that differences in results are insignificant.

Determining RD from field plots and previous stand examinations on the Powers R.D. indicates that, overall, the system is relatively accurate in categorizing stand density. It is not perfect, however, and the data from some plots and stands do not fit particularly well in regard to indicated RD, radial growth and diameter.

If Hall's GBA is accepted as biologically real because it provides a site specific index of stockability then RD is different since its index number has broad application to differing stand conditions. This does not make RD or the silviculture prescription based partly on it unreal biologically. Rather, RD should be considered one step in a process where biological and non-biological concerns are identified and accounted for so that the resulting silvicultural prescription represents an integration of these two important concerns. This paper documents one such process.

Relative Density Percent Selection

After selection of a density index the next important decision is the relative density percentage which best reflects the point where undesirable inter tree competition begins. Various research publications differ on the best figure. Curtis (1981) suggests that a RD of 50% will avoid suppression mortality and reduced crown development. The default thinning regime of DFSIM uses this percentage. Drew-Flewelling (1979) suggest use of 55% as a point of undesirable competition but stresses that this is tentative and not supported by definite research. Table 2 infers that a 55% relative density for Drew-Flewelling is equivalent to a RD (Curtis) of 60 to 65%. In conversation with Walt Knap, R-6 Mensurationist, he indicated that a firm relative density figure has not been established but that 60% should be considered an upper limit until additional information/research proves otherwise. Plots taken on the Powers Ranger District to tentatively "calibrate" relative density indicated very good radial growth at higher than expected relative densities. One 42 year old stand (site index 140-100 year base) had an average relative density (Curtis-R.D.) of 60% with an average live crown ratio (dominant and co-dominant trees) of 48%. The radial increment of codominant and dominant trees was approximately the same (33/20ths of an inch). For the rest of this paper a desirable relative density of 60% will be assumed. Importantly, a working relative density should be established for each District based on field plots in stands nearing the age of the first commercial thinning. Appendix A provides a sample of the data needed and calculations necessary to determine relative density. Stand examination data can be used as long as the silviculturist can relate the relative density measure with crown ratio and the current periodical radial growth.

Determination of Desirable Spacing

There are three different formulas which can be used with Curtis's RD. These are:

(1) $RD = G / D^{1/2}$

(2) $G = RD \times D^{1/2}$

(3) $N = RD/(.005454 \times D^{3/2})$

Where:

RD = Relative Density in percent

G = Basal Area (Sq. Ft.)

D = Quadratic Mean Diameter (Inches)

N = Trees Per Acre

To determine spacing, a desirable RD and diameter at the first commercial thinning (D) must be selected. In the following example a RD of 60% and D of 13.5 inches were selected. Using formula (3): $N = 60/(.005454 \times 13.5^{3/2}) =$ 221.8 (222) trees per acre or a spacing of 14 feet. Once a tentative spacing has been determined DFSIM runs should be made to refine these results at the desired relative density.

VARYING SITE CONDITIONS

Examination of timber stand profiles adjacent to clearcuts on relatively steep terrain will often show a site gradient from draws to ridgetops. This difference is indicative of the varying site conditions that can be expected in many stands. On the Powers Ranger District it is not uncommon to measure site class II (100 year base) productivities near the streams and site class IV or V on the ridge within the same stand. Site also varies in small intermixed areas depending on whether the topography is concave or convex (Tarrant - 1950) with the latter often having significantly lower productivities. Changes in aspect from north to south will produce this same effect.

These differences are not significant in old growth management since time has produced merchantable sized trees in all areas. The same is not true in second growth management. Without the amelioration of time, site differences will produce larger timber with greater relative densities in one area and smaller timber with comparatively lower relative densities in another. The problem is that with significant differences the better sites will reach desired size and relative densities earlier than the poor ones (Reukema-1977). If commercial thinning is delayed until the latter's excess trees reach merchantable size then the better sites will become overdense and less capable of responding to release.

There are three solutions to this problem.

1) Stratify lower site areas and where feasible plan to commercially thin them separately at a later time.

2) Where significant amounts (one third or over) of lower site areas are intermixed with higher sites such that they cannot be managed separately, anticipate advances in logging system economics to allow commercial thinning of both size classes at the same time.

3) In the same situation as 2), widen the PCT spacing of the entire stand to allow the poorer sites more time to grow before the better sites become over dense.

Table 3 illustrates the scope of this site differential problem. The data is derived from DFSIM runs (trees 7.6"+) which were manipulated to determine the age when a relative density of 60% was reached.

TABLE 3

Site Index 100 Yr. Base	Crop Trees Per Acre After PCT	Age at 60% RD
110	300	56
120	300	53
130	300	51
140	300	49
150	300	45

From additional DFSIM runs it was found that increasing spacing from 300 to 250* crop trees per acre caused a 2 year delay in reaching a relative density of 60%.

*DFSIM prints a warning message that stands thinned to less than 300 trees per acre are questionable extrapolations of the model due to a lack of data upon which it (the model) was developed. DFSIM was designed, however, to provide yield estimates based on specified parameters including trees per acre (Curtis - 1981). Robert Curtis (1985 P.C.) was consulted concerning the validity of simulations begun with fewer than 300 stems per acre following PCT. He suggested making several simulations with various initial stocking levels to determine if the progression of values at the first CT, particularly quadratic mean diameter, are consistent and logical. This has been done and the results are described in the yield considerations section.

Based on the above information it seems prudent to stratify stands into lower and higher site areas whenever they are capable, from a logging systems view point, of being managed separately at the time of commercial thinning. Many or most stands, however, have intermixed site indexes which cannot be so stratified. Under these circumstances having larger target diameters (13" to 14") and consequently greater PCT spacing (generally less than 300 trees per acre) provide the flexibility to accommodate normal site variation within the same stand. For stands with large site differences (more than ± 2 site index classes from average, over 1/3 or more of stand area) a combination of increased spacing and anticipated improvement in logging economics at the first commercial thinning will be necessary. For example, if a spacing of 250 trees per acre has been prescribed to achieve desirable stand diameters but large, intermixed site differences have been detected, then a spacing of 200 crop trees per acre might be selected. Increments of 50 trees per acre have been used above since this provides a desirable difference in spacing that the PCT contractor can relate to and "fits" with current contract practice of 1/50th acre inspection plots. Use of 1 foot differences in spacing are also workable. While trees per acre are used above, and elsewhere in this paper, it is intended that this indicates a desirable spacing (300 TPA = 12' x 12') rather than a desired average stocking which is affected by "holes" and other stand variation.

YIELD CONSIDERATIONS AND WOOD QUALITY

Yield Considerations

Setting stand management objectives to enhance harvest economics at the first commercial thinning will likely result in crop tree spacing at or below the range currently used. Before making a decision to implement these reduced stocking levels (such as 250 or 200 trees per acre), yield and wood quality concerns must be considered. This was done in a report (Lundgren - 1981) on red pine which analyzed the effects of initial spacing on yield, wood quality and economics. The results of this study indicated that establishment of 200 crop trees per acre enhanced harvest economics without unacceptably affecting yield and wood quality. These results cannot be directly applied to Douglas-fir but indicate that lower than normal stocking may produce similar acceptable results in this Region.

The ideal method of establishing larger stand diameters with acceptable yield tradeoffs would be economic analysis based on DFSIM. However, simulations beginning with less than 300 stems per acre are described as questionable extrapolations of this model. With this caution in mind, the data in Table 4 was generated from DFSIM runs with the objective of displaying the progression of values as trees per acre following PCT are reduced. The first commercial thinning is timed when a relative density (RD) of approximately 60% was reached.

TABLE 4

CTPA AFTER PCT	DBH AT 1st CT 7.6"+	DBH AT HCC 7.6"+	CT VOL. CUT .9 d/D *	HCC VOL. CUT *	TOTAL VOL. CUT *
400	11.8"	18.2"	2,004 7,789	12,003 68,426	14,007 76,215
350	12.5"	18.8"	2,209 9,094	11,919 68,506	14,128 77,600
300	13.3"	19.7"	2,413 10,552	11,860 68,905	14,273 79,457
250	14.4"	21.1"	2,565 12,011	11,745 69,238	14,310 81,249
200	15.8"	23.0"	2,740 13,765	11,691 70,087	14,431 83,852
150**	19.2"	26.0"	3,057 17,267	11,416 69,803	14,473 87,070

*Top figure is cubic feet to a 4" top, bottom figure is scribner volume to a 6" top.

Assumptions: Site index 130 (100 year base), 1 commercial thinning, 85 year rotation.

**Included for comparison purposes - commercial thinning is questionable at this low stocking level.

From 400 through 250 CTPA the progression of diameters and volume yields seems relatively consistent and plausible. The 200 CTPA figures begin to vary and those at 150 CTPA are inconsistent. This data also indicates that the major effect of crop tree spacing is on yield at the first commercial thinning (CT) with most of the spacings having essentially the same yield at the time of regeneration harvest.

As noted above, DFSIM prints a warning message when simulation is started with less than 300 crop trees per acre. This is not the case with DFIT and Table 5 was developed from this program to compare trends with DFSIM and Table 4. With DFIT, control of trees per acre is not direct but has to be accomplished by manipulating minimum merchantable DBH. While not displayed, this resulted in trees per acre for each spacing that were comparable between DFIT and DFSIM at the first CT.

TABLE 5

CTPA AFTER PCT	DBH AT 1st CT	DBH AT HCC	CT VOL. CUT .9 d/D *	HCC VOL. CUT *	TOTAL VOL. CUT *
400	11.9	17.3	2,070 8,233	10,568 59,737	12,638 67,970
350	12.6	17.9	2,196 9,223	10,370 59,199	12,566 68,422
300	13.3	18.7	2,248 9,825	10,242 59,125	12,490 68,950
250	14.0	19.2	2,362 10,739	10,042 58,389	12,404 69,128
200	15.0	20.0	2,513 11,990	9,781 57,339	12,294 69,329
150	17.6	21.8	2,478 12,899	9,541 56,876	12,019 69,775

*Top figure is cubic feet to a 4" top, bottom figure is scribner volume to a 6" top.

Assumptions: Site index 130 (100 year base), 1 commercial thinning, 85 year rotation.

These two models (DFIT and DFSIM) are based on different data bases. DFIT relies heavily on theoretical relationships with a more limited data base while DFSIM has functions which are based primarily on a large base of field data (Curtis-1981). With DFSIM, yield projections can be influenced relatively direct by trees per acre thru relative density while with DFIT, yield is influenced by desired diameters at the first commercial thinning. Curtis (1981) summarizes the relationship between DFIT and DFSIM by saying "...the most striking point is not that estimates differ in some respects but that two completely different analysis using different data have produced estimates which are remarkably similar. This tends to give confidence in both."

In tables 4 and 5 both DFSIM and DFIT show the same general relationship that yield increases slightly as crop tree stocking decreases following PCT. DFIT like DFSIM indicates that the major impact of PCT spacing is on the yield at the first commercial thinning with little effect on the period from commercial thinning to regeneration harvest. There is corroboration, then, between DFIT and DFSIM in that there does not appear to be a significant yield reduction at the 250 and 200 crop tree stocking levels. These findings, however, are at or somewhat beyond the "ragged edge" of reasonable estimates based on firm data. The following research results help firm up these implications.

Tappeiner et al (1982) reported on the 16 year findings of the Hoskins study near Corvallis, Oregon. The 8 treatments (9 including the control) in this experiment received 5 thinnings over a 12 year period resulting in stocking levels varying from 70 to 238 trees per acre (the control had 767 trees/acre).

Four years after the last thinning it was found that there were no significant difference in cumulative total cubic foot volume (Av. = 7,280 Ft^3) between the 3 lightest thinned treatments with final stocking of from 193 to 238 trees per acre. The unthinned control had significantly greater cumulative volume (10,620 Ft^3) however. The authors felt part of this difference was due to a late (Age 20) precommercial thinning of the treated plots. Since the control had an average DBH of 8.2" while that of the lightest thinned plots varied from 12.2 to 12.5", measurement of only potentially merchantable volume would probably have narrowed this difference significantly.

The authors felt these results demonstrated a considerable degree of flexibility over a wide range of stocking to achieve high yields with higher site (site index 160 to 170 - 100 year base) Douglas-fir.

Two other studies on lower productivity sites give <u>indications</u> that lower than normal stocking following PCT does not result in unacceptably lower yield. Reukema (1979) reported on a study established in 1925 with planted Douglas-fir stocking ranging from 4 x 4 to 12 x 12 on site class IV (100 year base) land. While cumulative <u>total</u> cubic foot volume declines slowly beyond the 10 x 10 foot spacing, merchantable volume begins to peak at the 12 x 12 foot spacing. While outside the range of data, it does not seem inappropriate to extrapolate that merchantable cumulative volume would not decline unacceptably at a 14 x 14 foot spacing (222 trees per acre). The author cautions against application of these research results to other areas but recommends use of the DFIT simulator to draw management implications.

Harrington and Reukema (1983) reported 25 year results of a precommercial thinning spacing study in S. W. Washington. Six treatments with stocking varying from 50 to 350 trees per acre were developed along with a control. Cumulative total cubic volume (stem volume) increased with greater stocking. With the exception of the 50 tree per acre stocking, however, net volume growth has narrowed such that the 100 tree per acre stocking has 90% the growth of the 350 tree per acre sample. While only total cubic volume was measured, the results would most likely be different if only potentially merchantable volume were considered. Based on these results the authors felt that wider than usual PCT spacings particularly if done at the 10 to 15 year recommended age, are promising.

The above simulations and research results do not prove conclusively that lower than normal PCT stocking (less than 300 trees per acre) results in acceptable yield. One study, in fact, (Wiley and Murray 1974) found that 10 years following PCT a 600 tree per acre stocking had much greater merchantable volume than the 300 TPA stocking (2,961 cu. ft. versus 1,825 cu. ft.) and that the former's growth rate was nearly the same as the latter's. The preponderance of evidence, however, indicates that stocking levels of 250 or even 200 crop trees per acre results in at least acceptable or perhaps even enhanced merchantable volume growth. It does not appear, then, that yield considerations should serve as a constraint preventing the establishment of reasonable and economically efficient target diameters for the first commercial thinning.

Mortality and Thinning Shock

It is important to determine if reduced stocking levels acceptably affect stand mortality and thinning shock. A 25 year study (Harrington and Reukema 1983) comes close to providing a direct answer to this question. In S. W. Washington, a 27 year old site V plantation was precommercially thinned to various spacings (50, 100, 150, 200, 250 and 350 trees per acre). The results indicated that initially the effects of thinning were undesirable because of chlorotic foliage, sunscald and weather damage (broken tops, leaning trees, etc.). Over the 25 years since thinning, mortality has been minor with an equivalent of approximately 14 trees per acre dying. Mortality has been generally caused by snow breakage, sunscald, root rot and insect damage. Another report (Wiley and Murray 1974) found that mortality on 205 thinned plots averaged 1.5 trees per acre per year and was distributed by cause as follows: disease - 40%, weather - 36%, animals - 14%, other - 10%. The Harrington and Reukema study concluded that the indentified mortality was minor and not closely related to spacing except for initially more mortality at the 50 TPA spacing and recent increased mortality at the closest spacings.

The effects of thinning shock, however, (Harrington and Reukema study) were not minor. All thinned plots suffered retardation of height growth over a 10 year period. The most severe reduction occurred at the widest spacing (50 TPA). The other stocking levels (100, 150, 200, 250 and 350 TPA) had less loss which differed little between them. In terms of diameter growth only the widest

spacing exhibited a depression for the first five year measurement period. Based on their study, Harrington and Reukema concluded that significant thinning shock occurs when stands on poor sites are thinned heavily at a later age than is recommended (10 to 15 years). Due to later increased growth the effects of such shock are eventually overcome.

A recent concern regarding precommercial thinning of Douglas-fir is the incidence of black-stain root disease (Verticicladiella wageneri). A study (Harrington et al 1983) of this problem found that precommercial thinning of Douglas-fir was associated with increased incidence of black-stain probably by creating conditions favorable to the vectors which spread V. wagenerii. The study did not, however, find increased incidence of the disease at wider spacing. In fact a comparison of disease incidence by stocking level indicated an inverse relationship that did not prove to be statistically valid.

Wood Quality

Wood quality is of concern to some who fear that intensively managed timber will have excessively wide rings that will impair its value as lumber. Under some conditions this is a valid concern. What is of primary importance in this paper is the marginal effect on wood quality of reducing stocking by PCT below what is presently considered normal spacing (300+ trees per acre).

Specific gravity or wood density is very important in controlling the quality or strength of a wood (U. S. D. A. Forest Service 1955). While stocking level may indirectly affect wood density, two direct factors are the percentage of late wood (within growth rings) and the amount of juvenile wood (Panshin & De Zeeuw 1964). Increased thinning spacing will increase the width of the growth rings but the percentage of late wood is most directly affected by the pattern and timing of terminal elongation (Panshin and De Zeeuw 1964). Site class (incorporating climate and soil properties) then, probably has a greater effect on the percent of late wood than ring width.

Juvenile wood develops close to the pith and is identified by reduced cellulose content and excessive warping. It is associated with the action of the apical meristem. As the active crown moves upward, the percentage of juvenile wood formed decreases. If increased thinning spacing causes live crown ratios to be larger, then it has an effect on the amount of juvenile wood formed.

To integrate these factors, Professor McKimmy - O.S.U. College of Forestry, Department of Forest Products, (1985 P.C.) was consulted. He felt that on all but the very high valley bottom sites, crop tree spacing down to 150 TPA will not unacceptably affect wood quality from present normal levels (300 TPA and up). This agrees with a report on red pine spacing (Lundgren 1981) which analyzed the changes of specific gravity based on tree spacing and site class. It was found that increasing site index from 40 to 70 (50 year base) had 5 times the effect (decreased specific gravity) as increasing stocking from 200 to 1200 trees per acre.

Another concern is that wider PCT spacing will cause branches to be retained longer causing reduced wood quality and injury or increased maintenance cost to milling machinery. This problem was analyzed for red pine (Lundgren-1981) and it was found that initial density did not affect the number of branches and had only a minor effect on the size of those retained. Georgia-Pacific in Coquille, Oregon, has a mill designed for second growth timber. They were consulted in regard to the effect of knot size on their milling equipment and lumber quality. Blair Holman (Resource Manager) indicated that knot size has not been a problem with the second growth logs they have been processing and does not expect it to be in the future if tree sizes do not materially decrease and/or if there is anticipated improvement in milling equipment. Of interest, Rex Timberlands (a subsidiary of Georgia-Pacific) currently PCT's their plantations to a 13' x 13' spacing.

Presently, second growth timber with high growth rates (4 to 6 rings per inch) is being peeled and sawn into products such as core stock and 2 x 4's with acceptable results. As the percentage of fast growing second growth increases the market will adjust to its differing characteristics with new applications and products. Wood quality, then, does not appear to be a factor which should constrain most precommercial thinning prescriptions.

SUMMARY - FIELD GUIDE

Harvest Economics

1. The first commercial thinning will probably have economic external yarding distances of approximately 1200 feet. Beyond this distance, spacing prescriptions should consider that future commercial thinnings are not likely and that significantly fewer crop trees per acre (such as 150 TPA) should be left. This same concept should be applied to stands which are not planned for commercial thinning.

2. To insure that precommercially thinned stands will have economically sized excess trees at the first commercial thinning, establish target stand diameters of 13 to 14 inches.

3. If it is likely that a stand can be tractor logged during commercial thinning then target stand diameters can be reduced. The same is true for stands whose characteristics will support a chipping operation.

4. Product value (based on size) considerations will be adequately addressed by achieving stand diameters that facilitate harvest economics.

5. The above considerations are based on average market conditions over time. It is recognized that these conditions will fluctuate causing timber which is uneconomic to harvest at one time to become economic at another. For PCT prescription purposes, however, planning for expected average conditions seems to be the prudent course of action.

Stand Density Control

1. Curtis' relative density formula ($RD = G/D^{1/2}$) is recommended for use because of its simplicity, correlation with Reineke's Stand Density Index and the crown competition factor, use in DFSIM and independence of age, site quality and management actions.

2. A relative density percent to be used in determining the timing of the first commercial thinning should be established for each District based on field measurements. Appendix A contains a sample of data needed and calculations necessary to do this. A relative density of 60% is recommended by some as an upper limit for desirable density.

3. A manipulation of the relative density formula ($N = RD/(.005454 \times D^{3/2})$ can be used to tentatively determine the desired number of trees per acre following PCT. DFSIM should be used, however, to refine these results at the desired relative density.

Varying Site Productivities

1. As part of silvicultural examination prior to the PCT prescription, determination of site variation (using Kings site class tables) within a plantation proposed for treatment is recommended.

2. If significant variation is detected (one third or more of area - 2 site index classes) then determine if the different site areas can be effectively managed separately at the first CT. If they can, document this in TRI and leave the spacing prescription the same in both areas since future managers will probably commercially thin them at separate times.

3. If differing site areas must be managed together then widen spacing from that determined by harvest economics and also anticipate improvement in economics which will allow harvest of smaller excess trees in one area before the better sites become overdense.

Yield Considerations and Wood Quality

1. Based on DFIT, DFSIM and three research studies, it appears that selecting larger target diameters for the first commercial thinning has an acceptable effect on merchantable yield both board feet and cubic feet. Thus, spacing prescriptions of 250 or even 200 CTPA appear acceptable in terms of yield.

2. For stands precommercially thinned at the proper age (10-15 years), increased spacing does not significantly affect mortality and thinning shock.

3. Except on very high valley bottom sites, increased target diameters (and thinning spacing) does not appear to unacceptably affect wood quality.

Effect of Associated Species

The above factors have been developed to guide PCT silvicultural prescriptions in timber stands which are predominantly composed of Douglas-fir (70%+). In situations where there are greater amounts of associated species or these species have specific requirements then the guidelines will need to be modified as the silviculturist judges appropriate.

RECOMMENDATIONS

The foregoing summary presents the major recommendations for precommercial thinning prescription development. In performing the research for these findings two needs became apparent and are the basis for the following recommendations:

1. The DFSIM model should be modified so that simulations begun with less than 300 trees per acre represent the best available knowledge and estimates of the effects of reduced stocking on yield and stand development.

2. Modify DFSIM so that any given relative density can be input into the model to control the timing of the first and subsequent (if any) commercial thinnings.

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APPENDIX A

Data needed and calculations necessary to determine relative density and how this measure relates to observable and measurable stand growth characteristics.

Variable Plots

Plot data needed:

BAF - User's choice, 20 BAF is convenient.

DBH - One inch class if possible, all trees providing significant competition.

Crown Ratio - Measure for all estimated crop trees following CT.

Radial Growth - 10 year growth in 20ths, same trees as for crown ratio, note current change if any.

Subjective assessment of stand density on plot.

Sample Calculation of Relative Density (RD):

(1)	(2)	(3)	(4)	(5)
DBH	# Trees	BA/Ac. By DBH Class (2) X BAF	Sq. Ft. BA by DBH Class *	Trees/Ac by DBH Class (3) ÷ (4)
9	1	20	.442	45
11	2	40	.66	61
12	2	40	.785	51
14	1	20	1.069	19
16	2	40	1.396	29
19	3	60	1.969	30
20	1	20	2.182	9
21	1	20	2.405	8
		260		252

*$BA = .005454\ D^2$

D (Quadratic mean dia.) $= \sqrt{\frac{BA \div TPA}{.005454}}$

$D = \sqrt{\frac{260 \div 252}{.005454}} = \sqrt{189.16} = 13.8"$

RD (Relative Density) $= G/\sqrt{D} = 260/\sqrt{13.8} = 70\%$

Average crown ratio = 55%

Average radial growth = 37/20 of inch.

Subjective Assessment (of Plot)

One crop tree had significantly reduced current growth, but with high crown ratios and overall good radial growth 70% relative density on this plot seems acceptable but at the upper range.

Fixed Area Plots

Plot data needed:

Same as variable plot except substitute plot size for BAF.

Sample Calculation of Relative Density (RD):

(1) DBH	(2) Sq. Ft. BA Per Tree *	
10	.545	Plot size: 1/50 Acre
4	.087	
3	.049	
7	.267	
8	.349	
3	.049	
5	.136	
	1.482	

BA/Ac = (2) x Plot size reciprocal
BA/Ac = 1.482 x 50 = 74.1

Trees/Ac (TPA) = #per plot times plot size reciprocal
TPA = 7 x 50 = 350

$$D = \sqrt{\frac{74.1 \div 350}{.005454}} = \sqrt{38.8} = 6.2"$$

$$RD = G/\sqrt{D} = 74.1/\sqrt{6.2} = 30\%$$

The radial growth, crown ratio and subjective assessments are the same as for variable plots.

*$BA = .005454D^2$

The relative densities, crown ratios and radial growth for plots within the same stand should be combined for an overall assessment. With data collected from 2 or 3 stands a determination of the desirable relative density to use on a particular District can be made with some degree of confidance. Subjective assessments are important to interpret both plot and stand average data.